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SHOWER WATER RECYCLE III. MICROFILTRATION STUDIES

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The U.S. Army Biomedical Research and Development Laboratory has investigated the use of polypropylene hollow fiber crossflow filtration cartridges for treatment of shower waters for recycle. Although the membrane has a nominal pore size of 0.2 micron, consistent removals of 60-90 percent of total organic carbon (TOC) and better than 99 percent of turbidity have been achieved from synthetic shower water containing 50 to 100 mg/L of TOC as soap. Although the system has not been optimized, a product flux of 0.5 gal/min per cartridge has given best performance. Recovery of treated water has exceeded 90 percent, but considerations of health and dissolved solids buildup will probably limit recovery to 80 to 90 percent in practice. This microfilter achieved complete removal of Klebsiella terrigena and 3.7 micron polystyrene beads used to simulate protozoan cysts.

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PREFACE

Chemical analyses were performed under the direction of Dr. Steven H. Hoke of the U.S. Army Biomedical Research and Development Laboratory (USABRDL). Microbial testing and bead counts were performed by Mrs. Helen T. Hargett. Ms. Lauren Berneski was a student at Hood College under contract to USABRDL during the period of performance of this study. The assistance of Ms. Rebecca Shatz in preparation of the manuscript is gratefully acknowledged.

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INTRODUCTION

This U.S. Army Biomedical Research and Development Laboratory (USABRDL) study addresses one of many technologies that may be used to treat shower wastewater for possible recycle. The Army and others have recognized that shower facilities for personnel may impose the greatest demand for high quality nonpotable water in the field. An 80-90 percent reduction in demand could be realized through development of this type of technology, and the concomitant reduction in wastewater would diminish the problem of insect vector breeding in discharge ponds. Questions concerning the safety of shower water reuse and the relationship of health of field personnel to frequency of bathing are addressed in a companion report.[1]

The Australian Army has an ongoing field study using a prototype trailer-mounted shower unit (Showering System, Field Mobile or SSFM) developed by Memtec Limited.[2] The SSFM provides eight shower heads and has the capacity to recycle 4,300 liters/hr (1,140 gallons per hr) of shower wastewater using a battery of 40 polypropylene hollow fine fiber microfiltration cartridges. Activated carbon adsorption is used for final polishing before disinfection. The Australian studies have emphasized operational concerns and troop acceptance; water quality parameters have not been addressed other than to assure adequate disinfection.

Intrigued by the concept that water-soluble soaps and other organic materials could be removed by a membrane with a pore size of 0.2 micron, USABRDL undertook to evaluate the Memtec microfilter with respect to removal of soap from a challenge water. A pilot scale test system comprising five microfiltration cartridges and a granular activated carbon filter was challenged with a synthetic wastewater consisting of 50-100 mg/liter of total organic carbon (TOC) as soap in Fort Detrick tap water. Microorganism removal was also studied.

EXPERIMENTAL PROCEDURES

Equipment

A Memcor Microfiltration System Model No. MS-0510 (Figure 1) was procured for this study from Memtec North America, 2033 Greenspring Drive, Timonium, Maryland 21093. The unit consists of five hollow fiber cartridges. Each cartridge is composed of an outer polyvinyl chloride shell, which encases polypropylene membrane hollow fibers, and a polyurethane potting compound (Figure 2). A 1 cubic foot model carbon filtering tank, known as a Park Tank (Figure 3), was purchased from Culligan Water Conditioning, Hagerstown, MD. This was added at the end of the MS-0510 system.

Analytical Methods

Total organic carbon (TOC) was determined with a Beckman model 915 B Tocomaster TOC analyzer. For pH determination, an Extech model 609 pH digital meter was utilized. Turbidity was determined with a Hach Model 2100. Chemical oxygen demand (COD) was determined using method 410.4 in Methods for Chemical Analysis of Water And Wastewater, USEPA 600 4-79-020. Alkalinity was

determined using method 309 B from Standard Methods (ed.15)[3]. Hardness was determined using method 309 B ethylenediamine tetraacetic acid (EDTA) titrimetric method from Standard Methods (ed.14)[4]. Total solids (TS) were determined using method 209 A (total residue dried) from Standard Methods (ed.15)[3].

Preparation of Test Waters

The test waters were made up for this study in batches of 2200 gallons with various concentrations of Ivory® bar soap. Soap concentration of 75-150 mg/liter were used to approximate values found for actual shower waters[5]. Concentrations by weight for a single soap sample and shampoo versus TOC are presented in Figures 4 and 5 respectively, and in Table 1. The soap bars were first weighed and then as many bars as were needed to make a solution of the appropriate concentration were sliced into small pieces and placed in a large beaker. Low heat and stirring caused the soap to dissolve and form a thick soup, which was then added to an appropriate amount of dechlorinated water and mixed slowly to prevent sudsing. (It is important that dechlorinated water be used as make-up water for the test solutions, as the hollow fibers are sensitive to chlorine, and membrane failure could result from excessive exposure[6].) Shampoo samples (Johnson Baby Shampoo) were made up directly by weight.

During one series of tests (Appendix Tables B5-B8) potassium chloride was added to the feed waters, resulting in an increase in conductivity, in order to determine if salts were removed by the membranes. This was discontinued when no reduction in conductivity was noted in the product waters.

TABLE 1. Concentrations of Soap and Shampoo vs. TOC

TOC Conc. mg/liter	Soap Conc. mg/liter	TOC Conc. mg/liter	Shampoo Conc. mg/liter
355.0	1,000	77.0	1,000
305.0	750	57.0	750
190.0	500	38.0	500
157.0	400	31.0	400
110.0	300	22.0	300
67.0	200	14.0	200
30.0	100	6.5	100
10.0	50	3.5	50
3.0	20	2.5	20
1.0	10	2.0	10
1.0	0	1.0	0

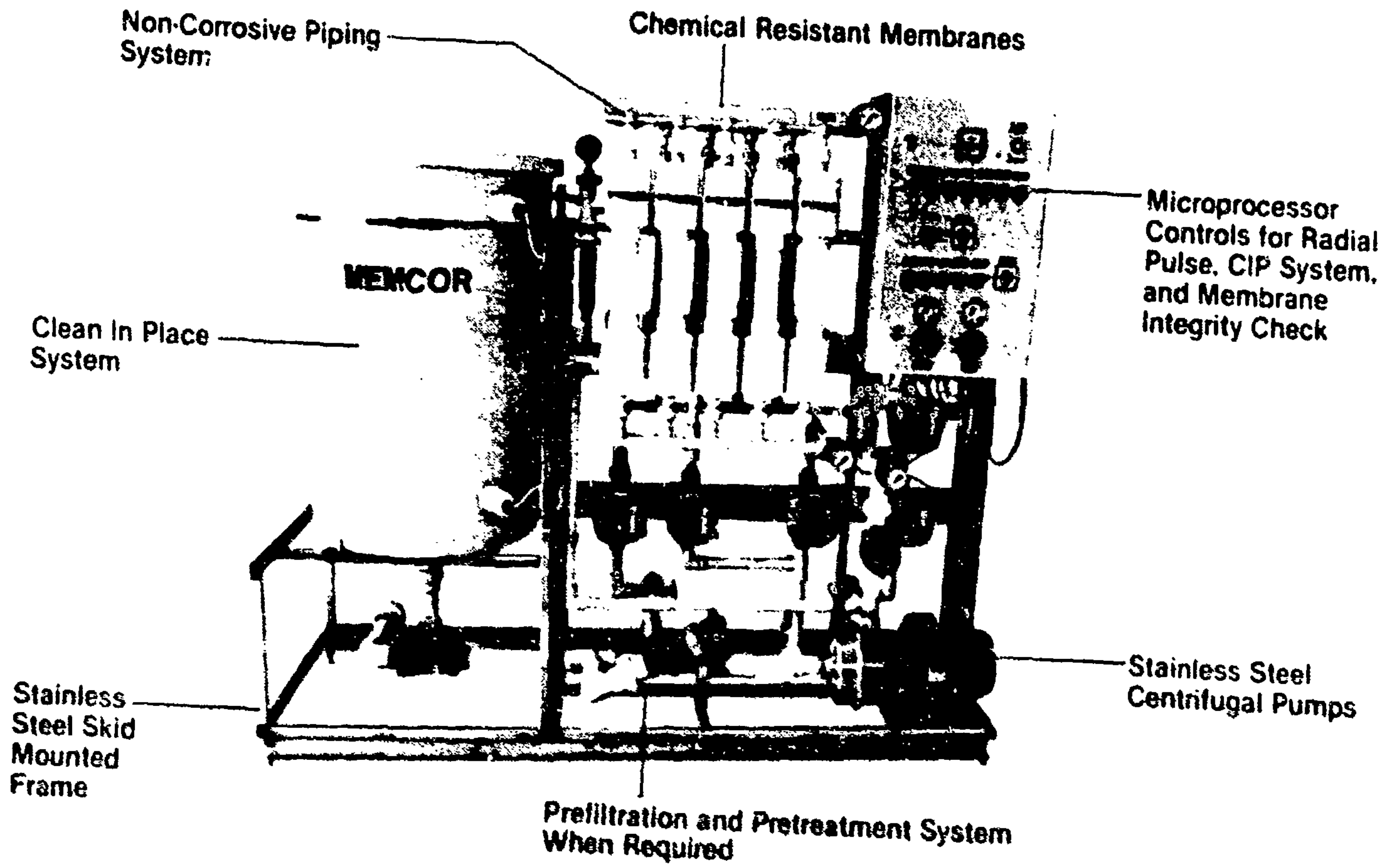

Photo Courtesy Memcor Corp.

Figure 1. Memcor Microfiltration System

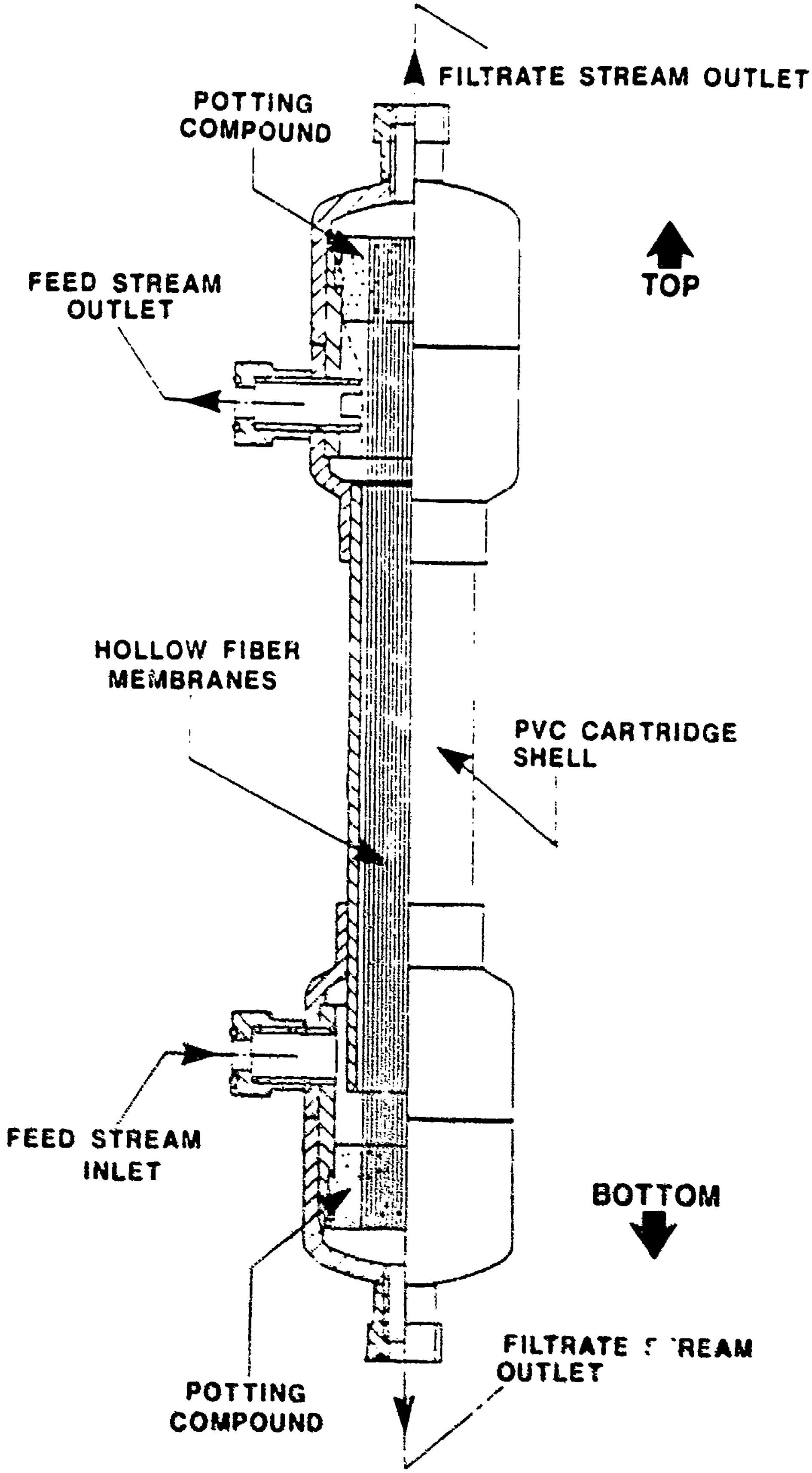

Figure 2. Filtration Cartridge

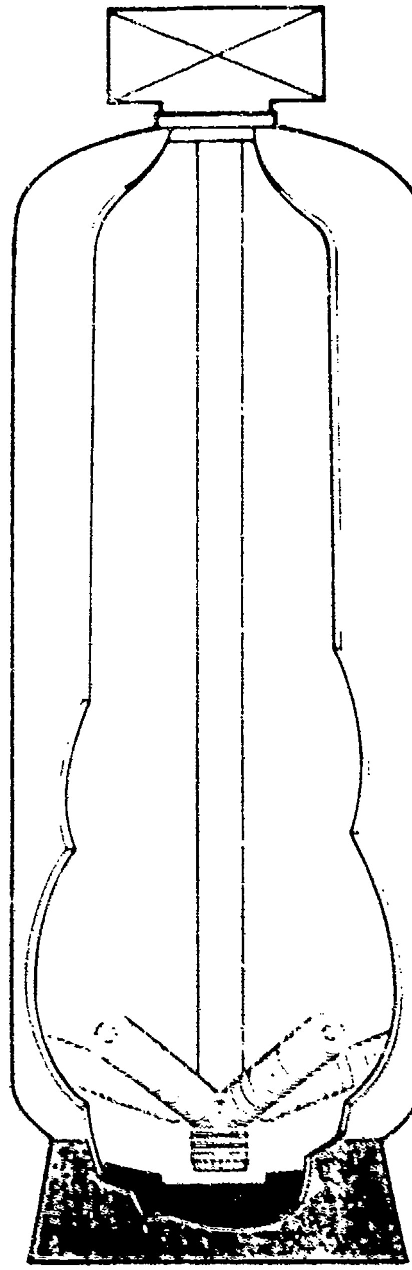

Figure 3. The Park Tank and Assemblies

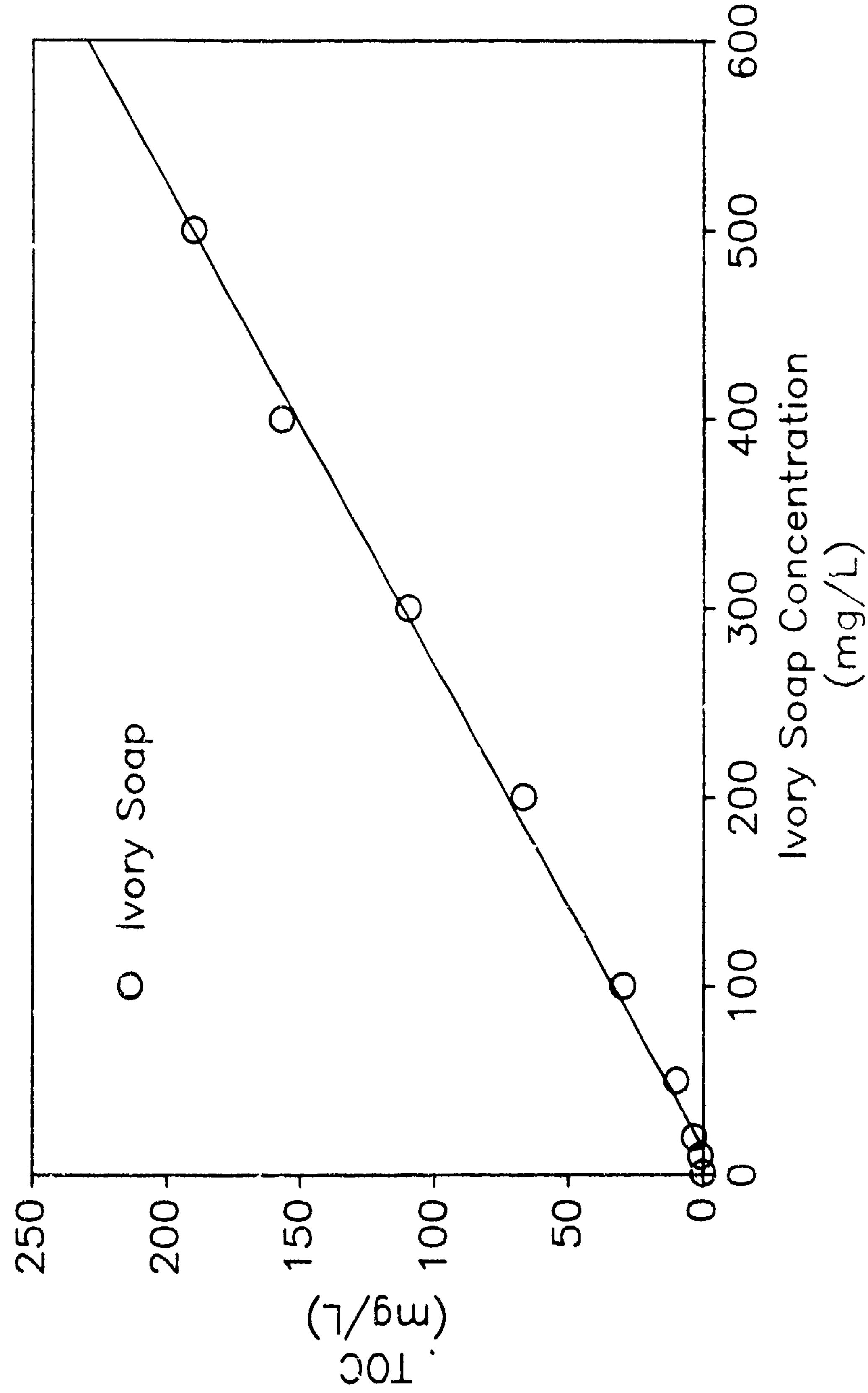

Figure 4. Soap TOC

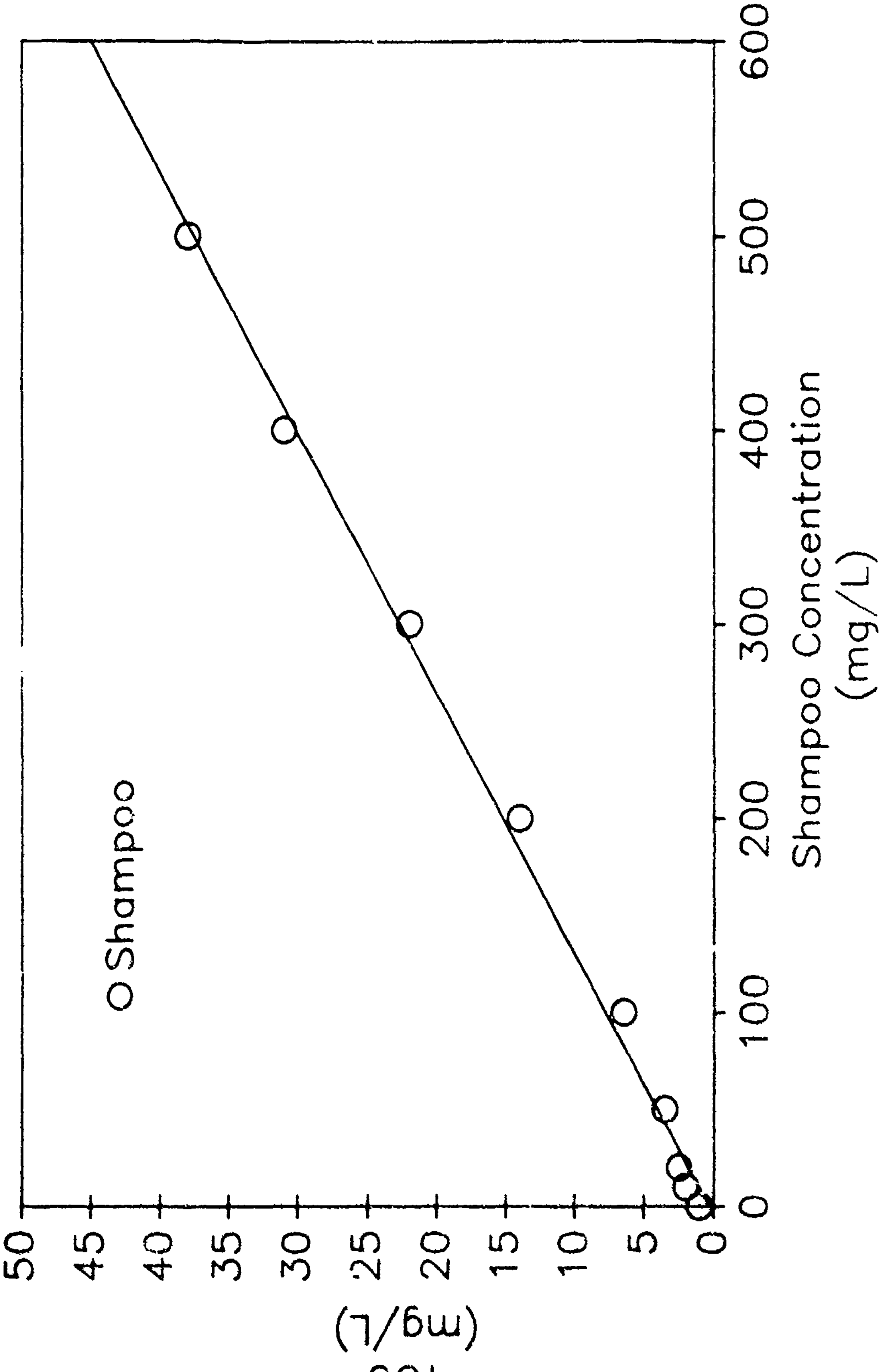

Figure 5. Shampoo TOC

Microfilter Operation

System Design

The feed stream of the Memcor unit is first run through a wire mesh screen to remove large particulate materials, in order to protect the pump and the hollow fibers. The feed stream then flows from the bottom of the cartridge along the outside of the hollow fiber membranes and exits through the top of the cartridge (Figure 2). The stream that passes through the membrane (the filtrate) exits the cartridge at both top and bottom. Rejected material builds a coat on the outside of the hollow fiber membrane. A pressurized air system (600 kPa) periodically is activated counter-flow to remove this build-up and to regain lost flow rates. The computer controlled system can be programmed to vary the frequency and duration of these backwash pulses.

Flow Rates

Initial studies at the maximum advertised flow rates of 4 to 5 gallons per minute (gpm) per cartridge (Figure 6), using a test solution of 100 mg/liter of Ivory® soap, resulted in severe blinding of the membrane filters, which could not be corrected by reverse air pulses. In Figure 7, the soap buildup can be seen. The residual material, shown in Figure 7, appeared to be composed of the insoluble soaps of calcium and magnesium. Next, flow was dropped to a rate of 2 gpm per cartridge. The results of all these early runs can be found in Appendix Tables A1-A29 and B1-B13. After repeated runs and consultation with Memcor representatives, it was established that the cartridges work best at a flow rate of 0.5 gpm, giving a total unit flow of 2.5 gpm of product water. A flow rate of 0.5 gpm per cartridge was used for all bead and microbial testing (Appendix Tables C1-C3).

Backwash Optimization

The number of backwash pulses in a cleaning cycle, the seconds the pump ran to flush the cartridge, and finally the seconds of exhaust before product water flow resumed were varied. Appendix Table A12 lists the combinations of times that were tried, and Tables A1-A29 show the results of this backwash optimization exercise. The percent of water lost to the backwash cycle was calculated and is also shown for each run. During these runs the average flow was above 10 gpm, the product turbidity was less than 1 nephelometric turbidity unit (NTU), and membrane pressures indicated that the cleaning was effective. The optimized backwash program appeared to reduce the tendency for blinding of the microfilters.

Sampling

Filtrate samples were collected directly from the unit on all early runs. On the last runs (Appendix Tables C1-C3), samples drawn as they left the unit are referred to as BC, to designate samples drawn before the carbon filter column, while samples taken after the carbon filter system are referred to as AC, for after carbon. All bead and microbial samples were collected before the carbon columns. The physical chemistry samples were taken both before and after passing though the activated carbon filter system.

Dimensions

Length (excluding connectors): 20.75"
Width (at ends, excluding connectors): 4.25"

Materials

Shell : PVC or ABS
Hollow Fibers : Polypropylene
Potting Compound : Polyurethane

Surface Area

1.0 square meters, 3,000 fibers per cartridge

Maximum Operating Temperature

130 degrees Fahrenheit (55°C)

Chemical Resistance

OPERATION: pH 1 - 14
Consult MEMCOR for the compatibility of your particular liquid.

CLEANING: All detergents
Concentrated hydrochloric acid
Concentrated sodium hydroxide
All common CIP solutions
Consult MEMCOR for the optimal cleaning agent for your application.

Filtration Rate

Flux rates are dependent on temperature, viscosity, solids load and type of solids. Clean water streams can reach rates of 300 gallons per hour per cartridge. The flux for a particular stream can only be confirmed by testing.

Filtration Capability

MEMCOR hollow fibers have a porosity of [illegible]0% and a 0.2 micron (nominal) pore size which allows high filtration rates and excellent clarity. Generally, MEMCOR hollow fibers:

- remove all suspended material
- remove bacteria to a microbial plate count of 0 - 10 cfu per 100 ml
- remove some dissolved macro-molecules
- separate oil from water

Figure 6. Hollow Fiber Crossflow Filtration Cartridge Product Bulletin

Cartridge With Soap Build-up (Restricted Flow)

Clean Cartridge (Unrestricted Flow)

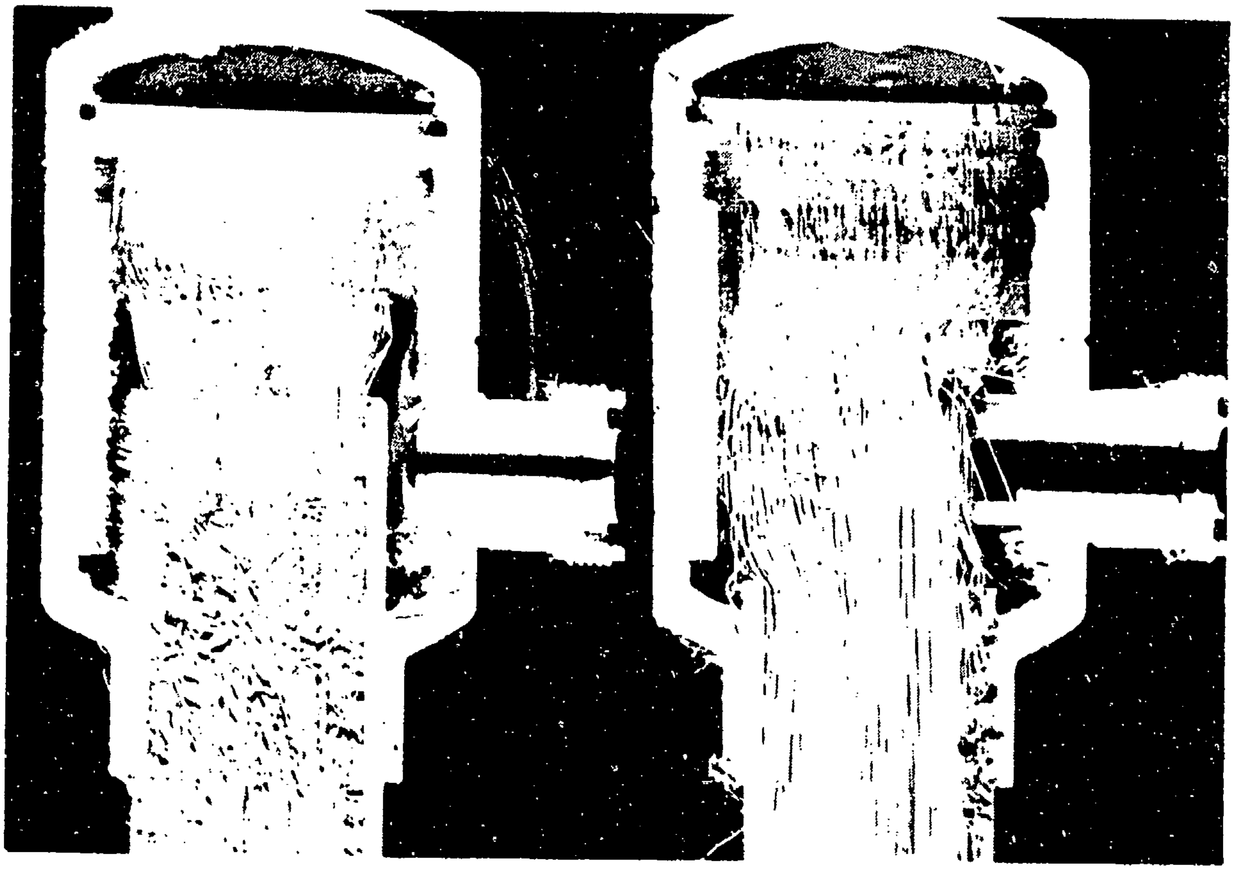

Figure 7. Memcor Hollow Fiber Crossflow Filtration Cartridge

Bacteriological Testing

Microbiological methods used are in accordance with the U.S. Environmental Protection Agency (USEPA).[7] Klebsiella terrigena (ATCC 33257) was grown 24 hrs at 36°C in nutrient broth to obtain a stationary phase culture. The culture was pelleted by centrifugation at 12,000 G, washed three times in sterile phosphate buffered saline (PBS) (pH 7.0), and filtered though a sterile Whatman #2 filter paper to remove cell clumps. A sample of the filtered bacterial cell suspension was diluted 1:10 in PBS and read in a Klett-Summerson photoelectric colorimeter. This reading was used to calculate the adjustment of the filtered bacterial cell suspensions to an optical density of 0.066, which yields 10^8 Klebsiella colony forming units (CFU)/ml. This filtered cell suspension was used as inoculum for the test water tank and was seeded at a concentration of 1 ml/liter of test water. Test water tank samples, which were collected at the beginning and end of the filtration run, were each diluted ten-fold in PBS. Samples were assayed by filtration of 1.0 ml through each of three 47 mm Millipore filters (Type HAWG, 0.45 micron pore size). Each filter was then placed on a 47 mm pad which contained 2.0 ml m-Endo broth MF (Difco) in a 50 x 9 mm snap-cap petri dish (Falcon 10066). Plates were incubated at 36°C for 24 hrs and counted. Filtered product water samples were assayed in triplicate by filtration of undiluted 1.0 ml, 10 ml, and 100 ml volumes through the 47 mm Millipore filters as described above.

Bead Testing

1. Background information:

a. 3.7 micron polystyrene beads called "AccuBead" made by Fastek (a Kodak Co.), lot number 965113 were used.

b. Due to the beads' tendency to adhere to glass and plastic, a surfactant, Tween 20 (polyoxyethylene-sorbitan monolaurate: Sigma catalog number P-1379, lot number 127F-0529), was added to samples to make a final concentration of 0.05 percent Tween 20. Results are presented in Table 3.

2. Sample treatment for bead recovery:

a. One liter samples were collected in polypropylene bottles. A clean catch method was utilized to collect samples from the effluent stream. Samples were then refrigerated until treatment.

b. Tween 20 was added to each sample to create a final concentration of 0.5 percent Tween 20.

c. The samples were centrifuged in a Sorvall RC20-B centrifuge fitted with a GSA head (rotor) for 10 minutes at 2500 rpm.

d. Pellets were not visible at this stage.

e. Approximately 950 ml of the supernatant was decanted leaving approximately 50 ml containing the beads.

f. This was washed into two 50 ml polypropylene centrifuge tubes using 0.05 percent Tween 20 in distilled water as a wash solution.

g. The samples were centrifuged for 10 minutes at 2000 rpm in the Damon/IEC PR-J centrifuge.

h. At this stage a small pellet was visible in the bottom of each tube.

i. The supernatant was decanted, leaving the pellet in about 1 ml of liquid.

j. The tube was sonicated in a Cole-Parmer sonicator for 1 minute to resuspend the pellet.

3. Solutions:

a. Decolorizer = 1 percent sulfuric acid.

b. Stain = 1 percent malachite green oxalate (Fisher catalog number M-290, lot number 746199).

4. Technique for bead count:

a. Solutions of samples from step J above were prepared for microscopic analysis according to the following protocol:

SAMPLE	VOLUME	STAIN	DECOLORIZER	TOTAL (in ml)
9-13	0.48	0.002	0	0.482
9-14	0.50	0.002	0	0.500
9-14F	0.001	0.001	0.002	0.004

b. Diluted sample was loaded into one side of the hemocytometer.

c. The hemocytometer was examined under oil immersion at 630x on a Zeiss microscope with a Nomarsky (phase interference microscopy) attachment.

d. The number of beads present in 5 large squares was recorded.

e. The other side of the hemocytometer was loaded and steps 2 and 3 were repeated.

f. The number of beads in the sample was calculated as follows: Number of beads found/number of squares counted x dilution factor x 10^4 (correction for the volume of the hemocytometer load) x volume (in ml) of the diluted sample = number of beads per liter of original sample.

RESULTS AND DISCUSSION

Chemical removal

The principal objective of this study was to evaluate removal of soap. Total organic carbon (TOC) values for feed water and product were determined at various times throughout this study. The theoretical ratio of TOC to soap is ca. 0.7 by weight, based on sodium palmitate; the actual ratio for bar soap is much lower and (in our experience) highly dependent on the length of time the soap is exposed to drying conditions. The USABRDL studies were designed to assure that TOC input levels were no lower than values found for authentic shower waters (30-40 mg/liter).[5] At high flow rates (4 gpm per cartridge, Appendix Tables A1-A11) a TOC reduction of about 60 percent was observed. At low flow rates (0.5 gpm per cartridge, Appendix Tables C1-C3 and Figures 8-10 and 11-13) reductions in organic content of 80$\pm$10 percent were achieved, as measured by either TOC or COD. Such a high removal of a water-soluble material by a 0.2 micron filter would be inexplicable unless, as we suspect, micell formation enhances removal, as has been noted for ultrafilters.[6] The activated carbon column used for these final runs appeared to have no substantial effect other than complete elimination of the soapy odor of the microfilter effluent. It must be noted that this study addressed soap removal only; the results should not be considered directly applicable to so-called bath or facial bars, which may contain most TOC in the form of anionic detergents.

Shampoos were not addressed in this study other than to establish a weight/TOC ratio for one common product, which was judged to be essentially dilute soap. It was decided not to investigate at this time the wide range of proprietary products with complex and variable chemical makeup.

The other standard wastewater parameters, i.e., hardness, alkalinity, conductivity and pH, were not substantially altered by microfiltration and would not provide a useful measure of system performance, except insofar as they relate to disinfection capability.

Turbidity Removal

For the first part of this study the microfilter was challenged using the aforementioned soap solution, with flow rates of 2 gpm per cartridge or higher. Turbidity reduction was generally excellent. The unit when functioning correctly consistently gave values of less then 1 NTU for soap solutions of 150 NTU, and for this reason system failure was best detected by turbidity testing. During run 4 (Appendix Table A4) a rise in turbidity was observed that was due to a valving problem. In run 5 (Table A5) high product turbidity numbers revealed a cartridge failure. Run 6 (Table A6) was carried out with all new cartridges installed, and we again saw low turbidities and good reductions in the TOC values. The USABRDL acquired a bubble point test kit from Memcor for checking cartridge integrity; but even with the help of a factory representative, we were unable to get reliable results using this apparatus.

Pathogen Removal

The unit was challenged with K. terrigena as simulant for bacterial pathogens and with a plastic bead that has been used by others[9] as simulant for protozoan cysts. Memtec had provided us with several papers that concerned the removal of bacteria.[10-12] Performance of the microfilter with respect to removal of K. terrigena at different times throughout the run is presented in Table 2. (The carbon unit was not used in this portion of the study.) Complete removal of K. terrigena was achieved through 45 minutes. The appearance of some colonies at 60 minutes may have indicated cartridge failure, or may have been the result of sample contamination. Total removal of beads by microfiltration is documented in Table 3.

TABLE 2. Removal of K. terrigena by Microfiltration

Sample Time (minute) (CFU/liter)	Sample	K. terrigena
0	Feed Tank	1.17×10^{8}
15	Product	0
30	Product	0
45	Product	0
60	Product	1.13×10^{1}
60	Feed Tank	1.13×10^{6}

TABLE 3. Bead Removal by Microfiltration

Date	Sample	Beads per Liter
9-13-88	Feed	1.13×10^{7}
9-13-88	Product	0
9-14-88	Feed	8.67×10^{4}
9-14-88	Product	0

System Performance and Reliability

Although the filter cartridges are rated as high as 5 gpm for clean water (Figure 6), the best performance for the soap solutions was obtained at a flow rate of 0.5 gpm per cartridge, the same as that used for the Australian field prototype.[2] The low output, 2.5 gpm for the five-cartridge test stand, made impractical our original plans to test the unit in the field. The last three runs (Appendix Tables C1-C3) were each 1 hr in duration at a flow rate of 0.5 gpm per cartridge. This run time was chosen so that the filtering effectiveness of the hollow fibers could be evaluated independent from the backwash system. It was found that an even flow rate could be maintained for 1 hr without backwashing the unit at the soap levels established in the test waters. Limited testing (Tables B9-B13) indicated that elevated feed temperatures (40^{o} vs. 17^{o}C) did not significantly affect system performance.

Various combinations of backwash frequency and duration were tested to optimize backwash conditions (Table A12). For a product flow of 2 gpm per cartridge, runs 21 and 22 (Tables A19 and A20) gave best results. This corresponded to a backwash interval of 10 minutes and a wasting rate of less than 10 percent. (The backwash procedure was not optimized for the lower flows judged most satisfactory for long-term runs.) Thus, water recovery for recycle can exceed 90 percent for the microfiltration, although health considerations would mandate a limit of 80-90 percent.[1] Repeated filter

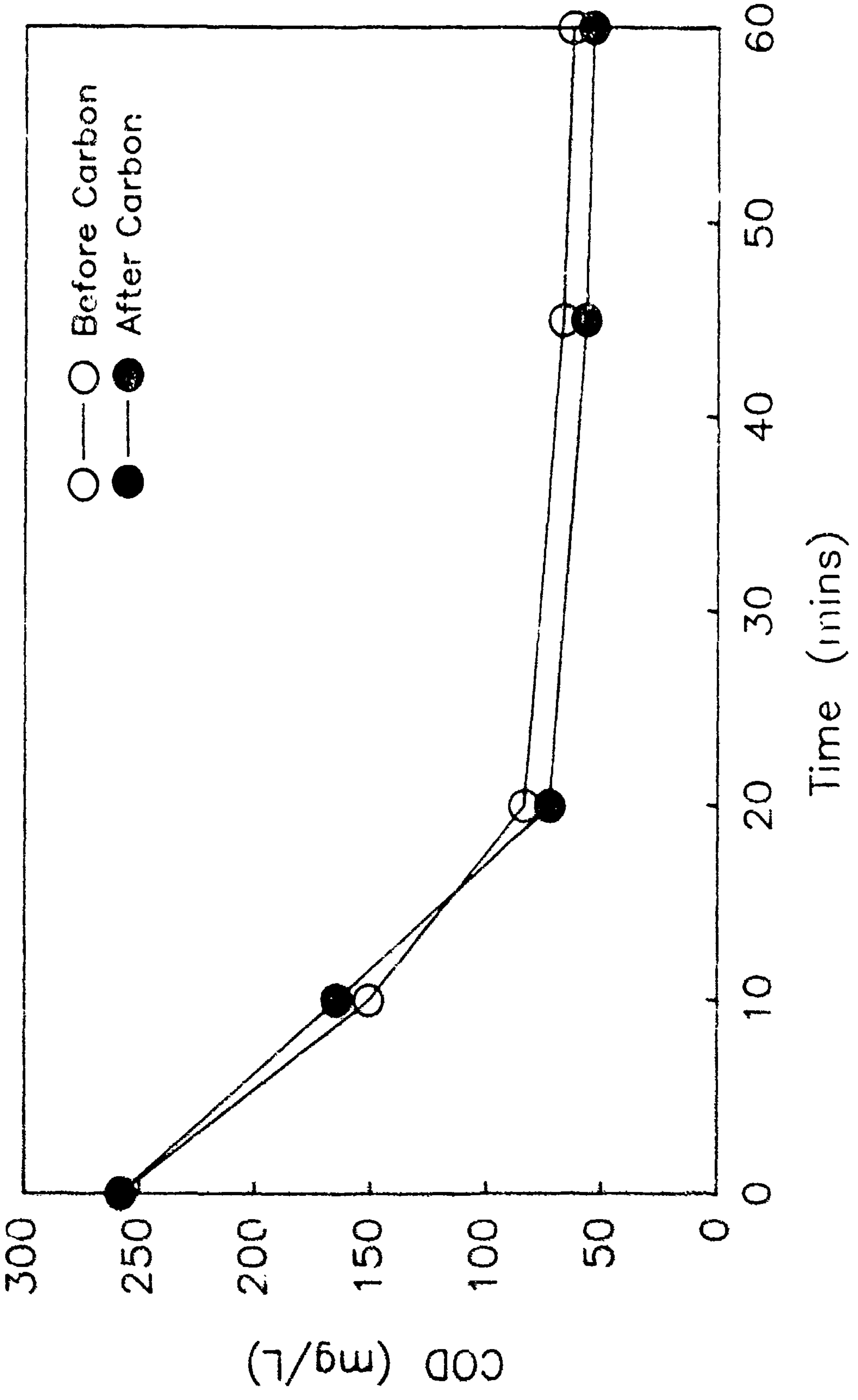

Figure 8. Chemical Oxygen Demand (COD), 17 Nov 88 Microfiltration Run

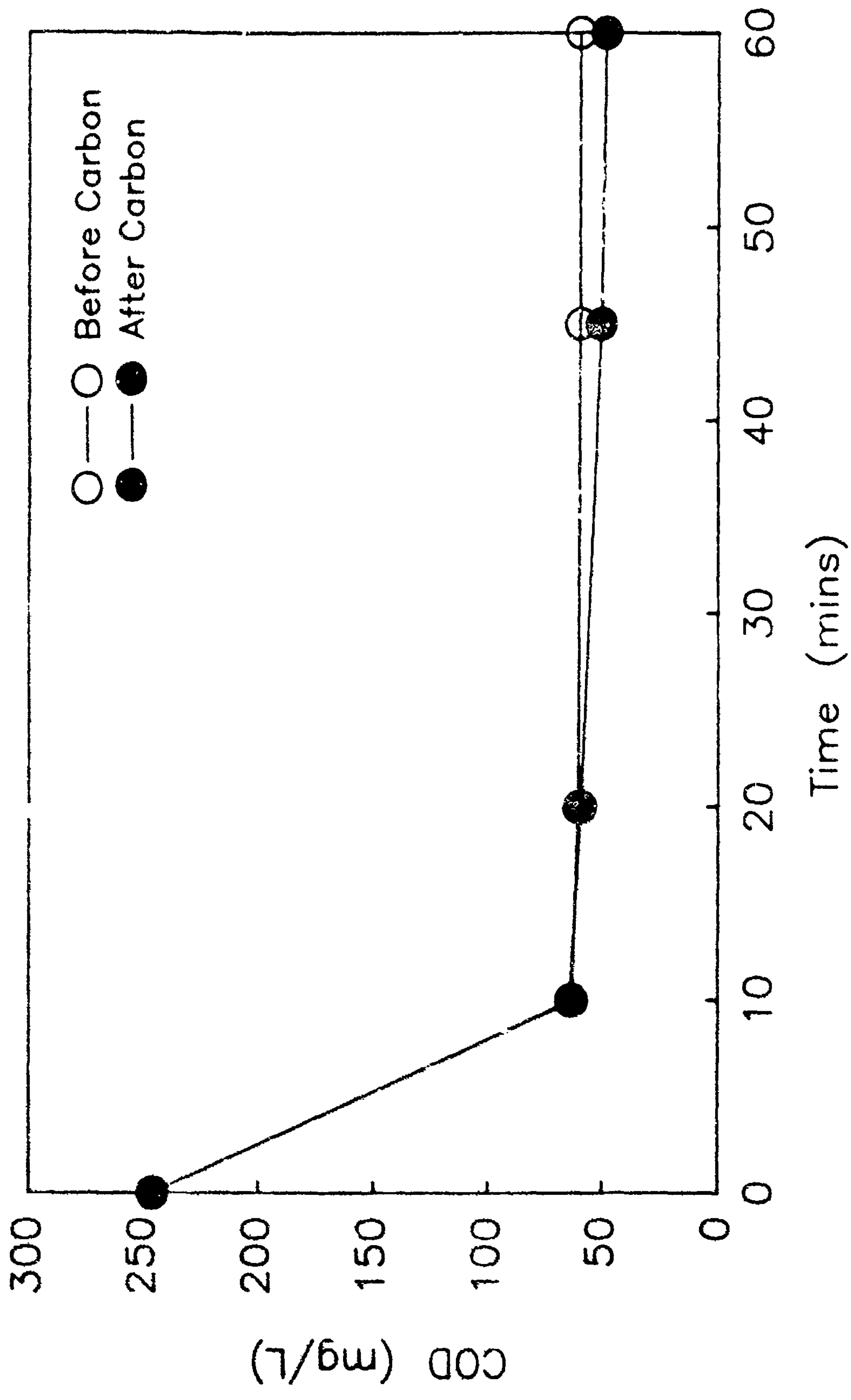

Figure 9. Chemical Oxygen Demand (COD), 18 Nov 88 Microfiltration Run

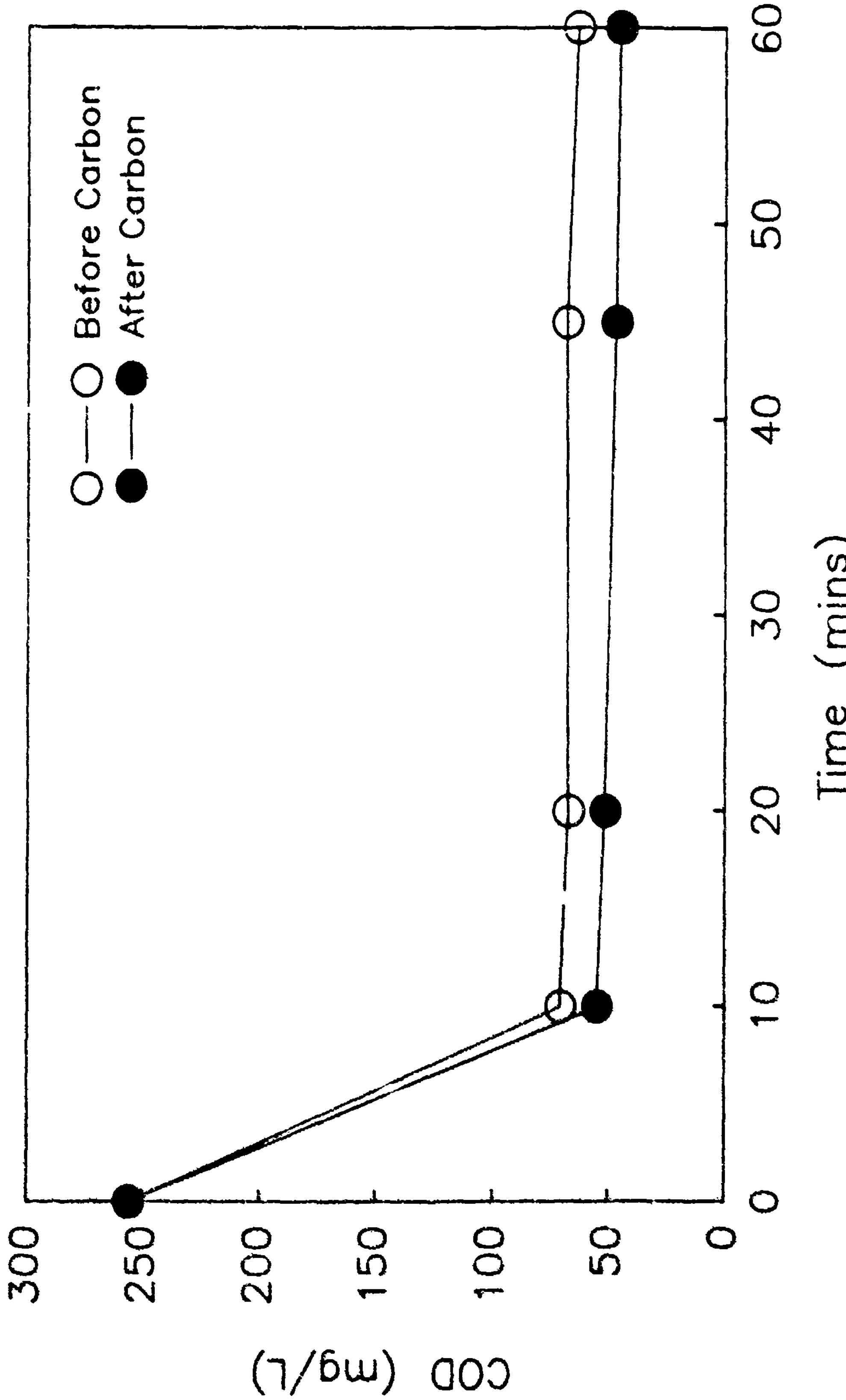

Figure 10. Chemical Oxygen Demand (COD), 19 Nov 88 Microfiltration Run

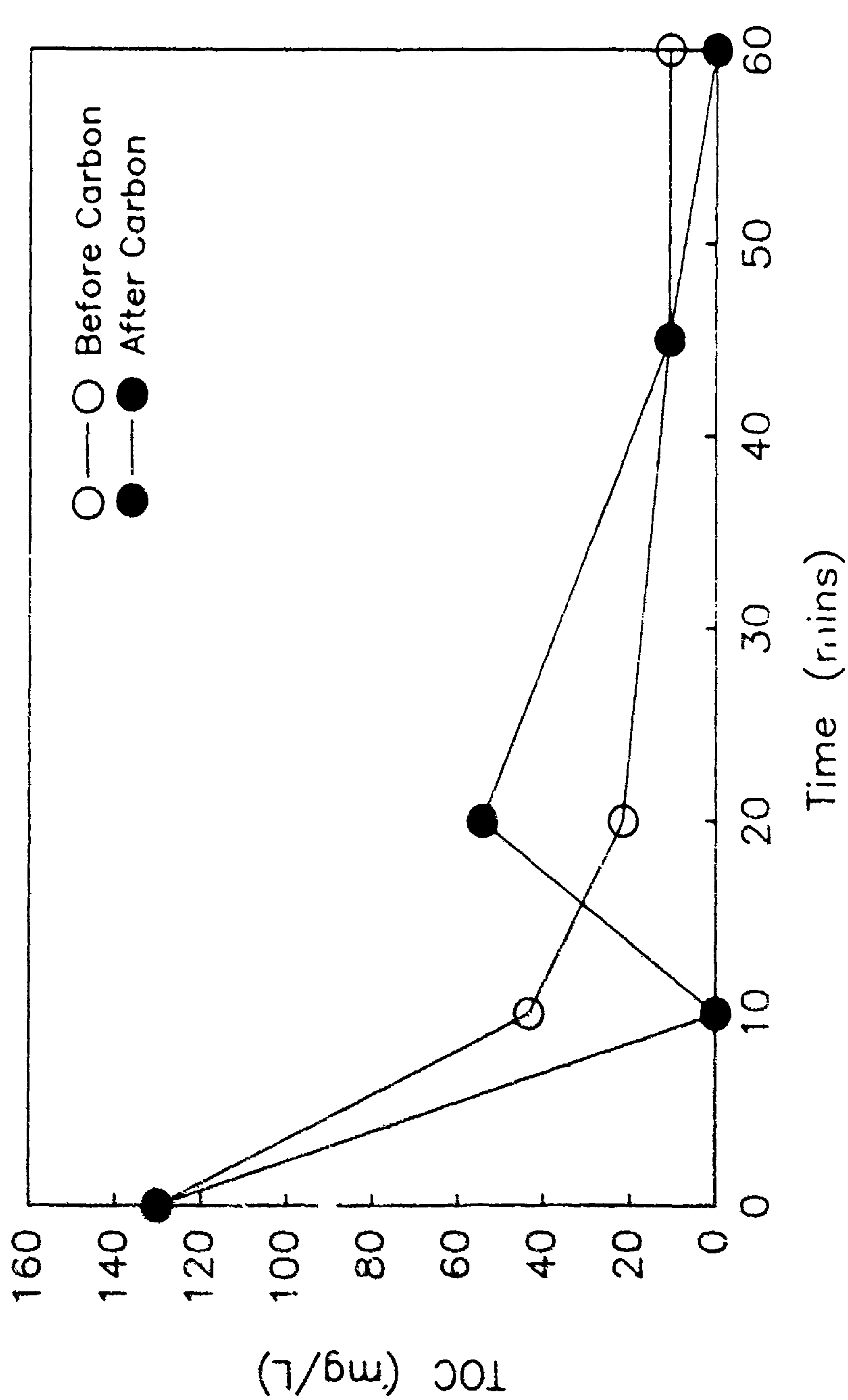

Figure 11. Total Organic Carbon (TOC), 17 Nov 88 Microfiltration Run

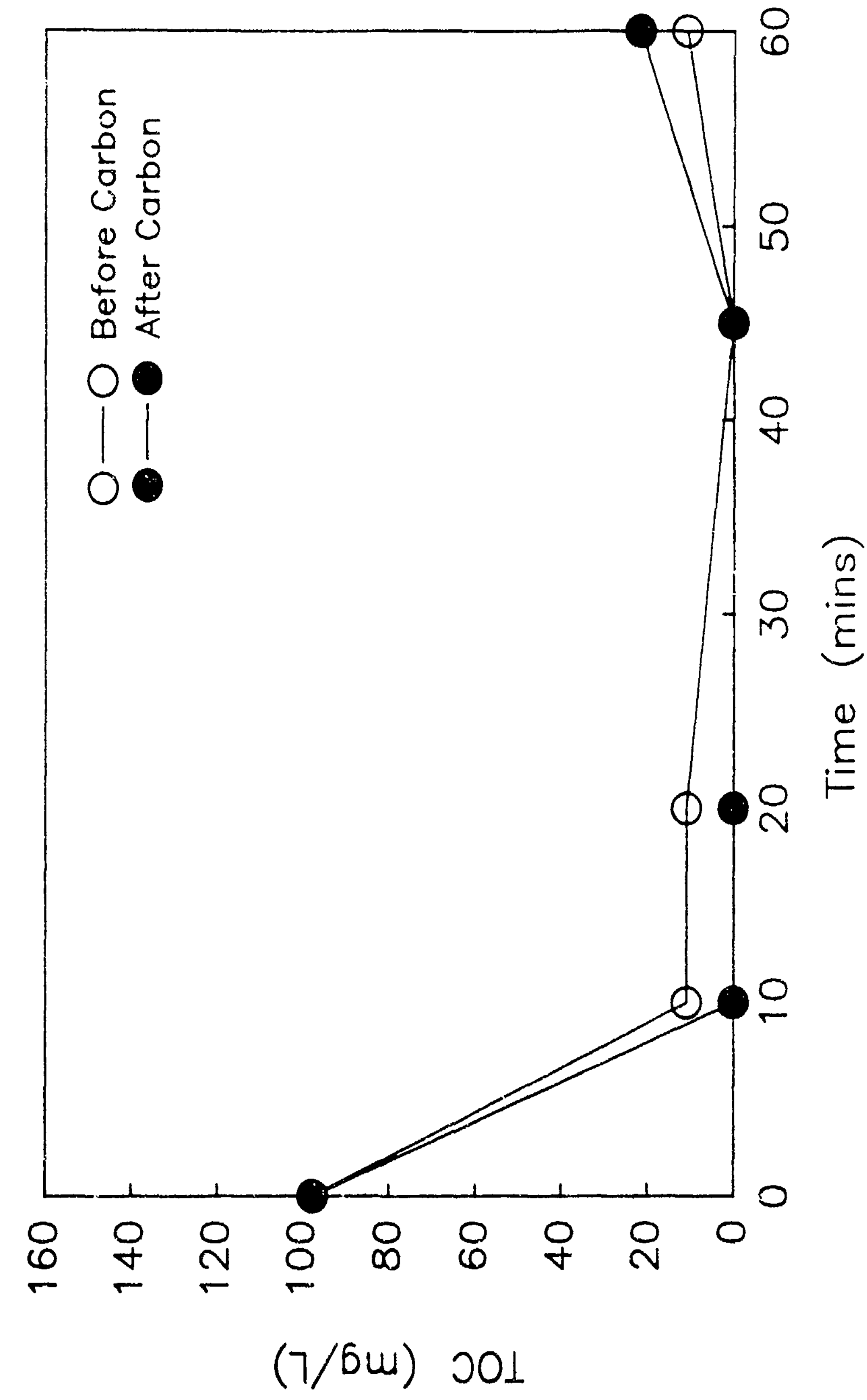

Figure 12. Total Organic Carbon (TOC), 18 Nov 88 Microfiltration Run

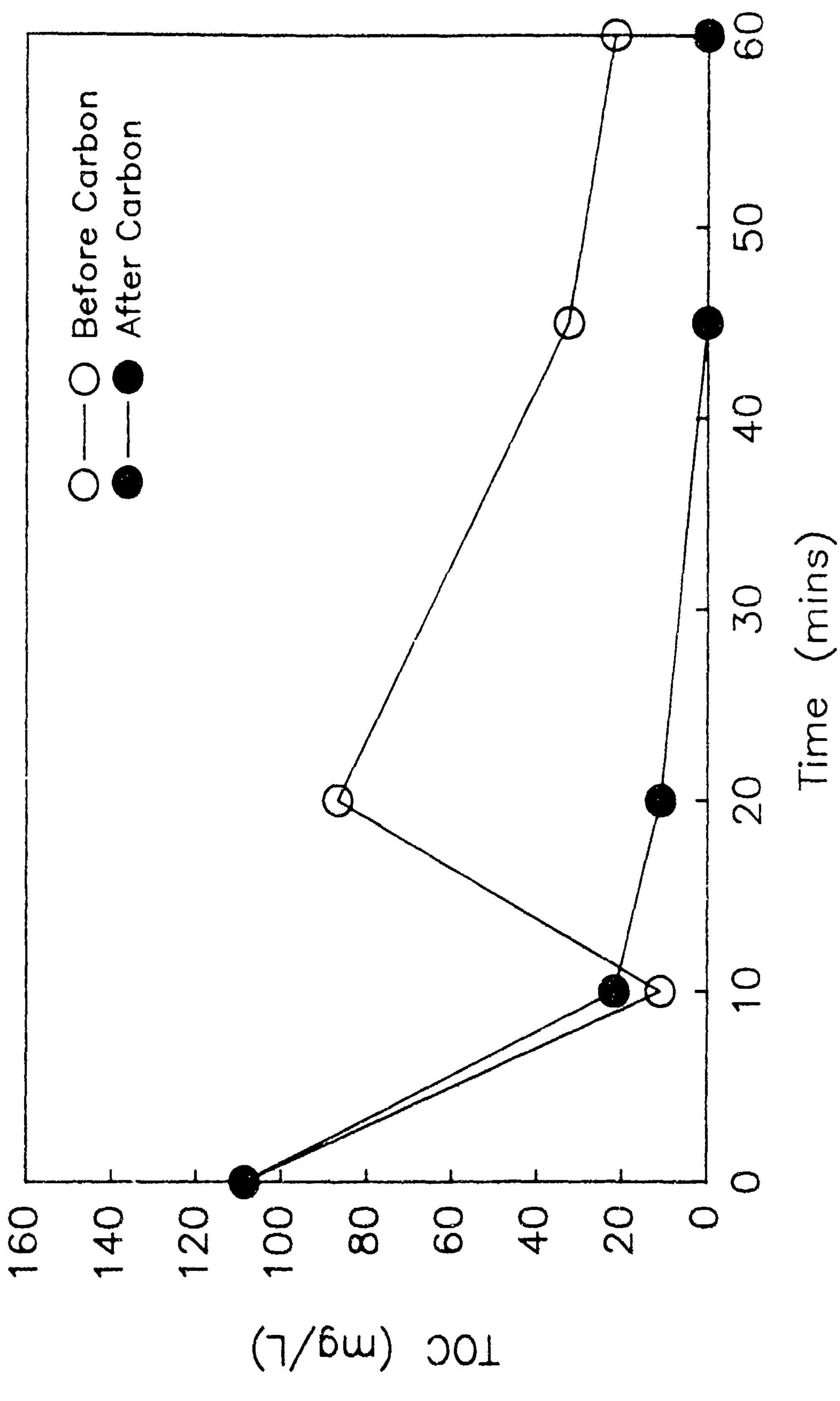

Figure 13. Total Organic Carbon, 19 Nov 88 Microfiltration Run

blinding and cartridge failures were experienced at the beginning of the study, presumably because the flow rates (2-4 gpm per cartridge) were too high for the soap concentrations used. Indeed, cartridge life throughout the study, generally less than 100 hrs, was much shorter then anticipated. At the higher flow rates cartridge plugging due to internal build-up of solid material, presumably calcium and magnesium soaps, was so severe that the air pulse cleaning system and cleaning agents were unable to bring the unit back up to new cartridge flow rates. Since this study was completed, we have learned that the soap used with the Australian unit includes a sequestering agent (EDTA), which probably prevents build-up of calcium soaps.[13]

CONCLUSIONS AND RECOMMENDATIONS

Turbidity removal is excellent for this type of system and would pass TB MED 577 (Table 4) standards with little difficulty. During our work with this system the integrity of the cartridges came into question at various times. We found that the turbidity was the most reliable sign of a problem. An in-line turbidity monitor would add greatly to the reliability of the system when used for wastewater treatment in a field situation.

TABLE 4. Recycled Water Standards (TB MED 577[a])

Constituent	Maximum Acceptable Limit
pH	6.5 - 7.5
Turbidity	5 NTU
Hardness	500 mg/liter
Free Available Chlorine[b]	5 mg/liter, >20° 10 mg/liter, <20°

a. Reference 14.
b. Target residual with a minimum contact time of 30 minutes.

The TOC and COD removals are generally in the 60-90 percent range, and 75 percent is probably consistently achievable for a flow rate of 0.5 gpm per cartridge. Recovery of treated water for recycle exceeded 90 percent under optimum backwash conditions. Multiple passes, i.e., addition of soap to the treated wastewater followed by retreatment, may not give the same TOC/COD reduction; this could be the subject of further study. The carbon filter seems to have little effect on either one of these parameters, although it did remove the soapy odor of the microfilter effluent. The principal function of the carbon filter is to remove potential organic contaminants[1] other than soap that may not be reduced by microfiltration.

The mechanical removal of waterborne protozoa and their cysts, bacteria and micellar-adsorbed viruses appears to be well within the capabilities of this technology. Chlorination of the product water would be required by TB Med 577 (Table 4). Disinfection was not part of this study, but earlier work has shown that a free available chlorine residual of 5 mg/liter will result in a total microbial kill for treated shower wastewaters.[5]

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APPENDIX A

High-flow (2-5 gpm/cartridge) and Backwash Optimization Runs

TABLE A1. Run 1, 3 June 1987

Time min	Flow gpm	Conductivity mMhos	pH	Turbidity NTU	Alkalinity mg/liter	Hardness mg/liter	TOC mg/liter
Feed		160	8.22	82.00	75.4	98	25.6
0	24.0	160	8.22				
3	22.0						
5	20.8	160					9.3
11.5	19.0	150					
15	17.5	165	8.17	0.18			
20	16.5	160			69.6		
25	15.0	150					13.2
30	14.0	170	8.17	0.22			
35	13.0	165					
40	12.2	150			63.8	96	
45	11.0	160	8.15	0.20			
50	10.5	175					13.6
55	10.0	160					
60	9.2	160	8.11	0.25	58.0		
65	8.5	160					
70	8.0	160					
75	7.0B [a]	155	7.98	0.28			
78	19.0						
80	14.5	155		0.20	61.5	97	
85	11.5	155		0.24			
90	9.5	160	8.09	0.26			
95	8.5	150					
100	7.8B	200		0.49	63.8		13.7
102	14.0						
105	10.5	200	8.07	0.39			
110	9.0	190					
115	8.0	185					
120	7.4B	150			63.8	102	
122	13.0						
125	9.5	155		1.05			
130	8.0B	150		0.58			
Unit shutdown for night, restarted 4 June, at 130 minutes.							
130	16.0	150	8.10	0.87			
135	12.0	210					
140	10.0	210			63.8		
145	9.5	210					
150	8.5	195	8.06	0.11			13.8
155	8.0B	200		0.15			
157	15.0						
160	11.0	200		0.68	58.0		
165	10.5	210	8.02	0.38			
170	9.0			0.28			

TABLE A1. Run 1, 3 June 1987 (continued)

Time min	Flow gpm	Conductivity mMhos	pH	Turbidity NTU	Alkalinity mg/liter	Hardness mg/liter	TOC mg/liter
175	8.5						
180	7.5			0.22	9.6		
183	7.0B						
185	14.5	200	8.04	1.05			
190	10.0						15.0

B = manual backwash.

TABLE A2. Run 2, 11 August 1987

Time min	Flow gpm	Conductivity mMhos	pH	Turbidity NTU	Alkalinity mg/liter	Hardness mg/liter	TOC mg/liter
Feed		340	7.25	84.00			49.4
0	20.0	340	7.27	0.30			
5	9.0	340	7.33	0.80			19.3
10	7.0B[a]	340	7.33	0.98			19.2
15	9.0	340	7.36	2.80			19.3
30	5.0B	340	7.36	0.15			18.5
45	4.0B	340	7.42	0.44			18.6
60	4.0	340	7.37	2.90			18.9
75	2.0B	340	7.29	1.20			
100	5.0B	340	7.37	4.20			17.9
125	3.0B	340	7.33	3.60			18.1
150	2.0B	340	7.31	2.20			10.5
175	2.0B	340	7.39	3.50			
200	2.0	340	7.40	2.60			15.7

B = manual backwash.

TABLE A3. Run 3, 13 August 1987

Time min	Flow gpm	Conductivity mMhos	pH	Turbidity NTU	Alkalinity mg/liter	Hardness mg/liter	TOC mg/liter
0	17.0	230	7.15	75.0			17.1
5	7.0B[a]	230	7.15	4.2			4.6
10	4.0	230	7.15	4.4			4.6
15	4.0B	230	7.15	3.5			4.2
30	2.0B	230	7.21	3.2			4.2
45	2.0B	230	7.24	4.8			3.5
60	2.0B	230	7.21	5.0			3.3
75	2.0B	230	7.27	2.2			3.2
100	2.0B	230	7.26	3.1			3.1
125	2.0B	230	7.29	1.7			3.2
150	3.0B	230	7.25	2.6			3.1
175	2.0B	230	7.31	2.0			3.1
200	2.0	230	6.13	1.4			3.1

B = manual backwash.

TABLE A4. Run 4, 18 August 1987

Time min	Flow[a] gpm	Conductivity mMhos	pH	Turbidity NTU	Alkalinity mg/liter	Hardness mg/liter	TDS mg/liter	TOC mg/liter
0	20.0	240	7.11	86.0	127.6	147	303.0	49.4
5	6.0	240	6.88	17.0	92.8	116	250.0	20.4
10	5.0	250	6.85	17.0	81.2	112	187.8	20.7
15	5.0	240	6.83	16.0	104.4	114	185.5	21.7
30	2.0	240	6.85	15.0	116.0	114	189.0	20.2
45	2.0	240	6.86	18.0	92.8	118	228.3	22.1
100	2.0	240	6.85	10.0	92.8	113	215.5	19.6
125	2.0	250	7.04	14.0	92.8	120	243.3	20.6
150	2.0	240	7.04	9.0	81.2	122	224.8	20.7
175	2.0	240	7.11	10.0	92.8	123	225.5	20.7
200	2.0	240	7.11	9.0	139.2	122	215.3	21.6

Automatic backwash, 5-minute interval.

TABLE A5. Run 5, 24 August 1987

Time min	Flow[a] gpm	Conductivity mMhos	pH	Turbidity NTU	Alkalinity mg/liter	Hardness mg/liter	TOC mg/liter
0	17.0	250	7.35	34.0	104.4	144	32.8
10	15.0	250	7.30	2.0	98.6	142	13.1
15	12.0	240	7.85	3.2	116.0	142	7.3
30	12.0	240	7.85	3.4	116.0	144	11.2
45	10.0	240	7.86	3.3	92.8	142	10.0
60	10.0	250	7.37	3.2	92.8	144	8.0
75	8.0	240	7.30	3.1	116.0	145	6.8
100	8.0	240	7.33	3.3	98.6	144	5.9
125	8.0	240	7.33	2.9	104.4	147	9.4
150	7.0	250	7.34	3.8	98.6	142	12.8
175	7.0	250	7.32	2.6	133.4	143	8.4
200	7.0	250	7.30	2.7	110.2	147	7.2

Automatic backwash, 5-minute interval.

TABLE A6. Run 6, 4 September 1987

Time min	Flow[a] gpm	Conductivity mMhos	pH	Turbidity NTU	Alkalinity mg/liter	Hardness mg/liter	TOC mg/liter
0	15.0	340	7.40	89.00			57.8
5	15.0			0.35			6.1
10	16.0			0.34			8.2
15	14.0			0.30			7.8
30	15.0	340	7.40	0.30			9.9
45	18.0			0.30			7.7
60	17.0	330	7.40	0.31			6.0
75	18.0			0.35			6.1

Automatic backwash, 10-minute interval; new cartridges installed.

TABLE A7. Run 7, 3 September 1987

Time min	Flow gpm	Conductivity mMhos	pH	Turbidity NTU	Alkalinity mg/liter	Hardness mg/liter	TDS mg/liter	TOC mg/liter
0					116.0	130	214.0	76.4
5					92.8	128	283.5	25.9
10					87.0	125	232.0	25.3
15					116.0	130	218.0	25.5
30					116.0	130	216.5	25.4
45					121.8	128	217.0	25.5
60					92.8	129	212.5	25.2
75					92.8	129	219.5	25.2

TABLE A8. Run 8, 10 September 1987

Time min	Flow[a] gpm	Conductivity mMhos	pH	Turbidity NTU	Alkalinity mg/liter	Hardness mg/liter	TDS mg/liter	TOC mg/liter
0	20	370	7.23	95.00	121.8	136	251.0	66.5
10	[illegible]			0.07				23.4
20	13[illegible]			0.06				24.3
30	108			0.09	104.4	122	224.3	25.0
40	8			0.08				24.4
50	8B			0.07				24.5
60	5B	360	7.23	0.14	127.6	122	232.0	24.2
70	5			0.11				24.8
80	7B			0.11				25.0
90	5B			0.08	110.2	128	236.8	25.3
100	5			0.07				24.8
110	4B			0.09				25.2
120	5B	350	7.25	0.13	110.2	124	222.8	24.4

B = manual backwash.

TABLE A9. Run 9, 11 September 1987

Time min	Flow[a] gpm	Conductivity mMhos	pH	Turbidity NTU	Alkalinity mg/liter	Hardness mg/liter	TOC mg/liter
0	18	360	7.01	130.00	116.0	138.0	11.4
10	17			0.70			25.6
20	14			0.06	110.2	131.0	24.7
30	11			0.07			25.3
40	11			0.07	127.6	121.0	25.2
50	11			0.01			24.5
60	10	340	7.08	0.07	110.2	123.0	24.2
70	10			0.20			24.5
80	10			0.08	110.2	126.0	25.5
90	10			0.10			24.5
100	9			0.08	104.4	120.0	24.3
110	9			0.07			24.8
120	9	360	7.14	0.07	104.4	125.0	24.5

Automatic backwash, 5-minute interval.

TABLE A10. Run 10, 29 September 1987

Time min	Flow[a] gpm	Conductivity mMhos	pH	Turbidity NTU	Alkalinity mg/liter	Hardness mg/liter	TOC mg/liter
0	15	390	9.60	90.00	99.8	52.0	44.8
10	14			0.16	113.7	54.0	11.5
20	12			0.13	104.4	54.0	11.1
30	11	380	9.90	0.15	88.2	53.0	11.3
40	9			0.14	111.4	54.0	11.3
50	6			0.23	99.8	50.0	11.6
60	6	375	9.80	0.10	92.8	52.0	9.8
70	5			0.10	92.8	52.0	11.1
80	3			0.06	90.5	50.0	11.7
90	3	390	9.70	0.07	92.8	52.0	10.9
100	3			0.06	92.8	50.0	10.9
110	3			0.06	92.8	50.0	11.0
120	3	380	9.90	0.09	81.2	48.0	10.9

Automatic backwash, 10-minute interval.

TABLE A11. Run 11, 6 October 1987

Time min	Flow[a] gpm	Conductivity mMhos	pH	Turbidity NTU	Alkalinity mg/liter	Hardness mg/liter	TDS mg/liter	TOC mg/liter
0	14	400	9.55	88.00	133.4	77.0	287.8	65.7
10	10			0.12	110.2	45.0	191.8	13.0
20	6			0.10	110.2	46.0	195.0	13.1
30	5	400	9.55	0.10	104.4	44.0	191.0	13.8
40	4			0.10	87.0	42.0	198.0	13.3
50	4			0.10	104.4	43.0	195.5	13.2
60	4	410	9.52	0.10	116.0	45.0	198.3	13.5
70	4			0.20	87.0	44.0	210.5	13.7
80	4			0.15	87.0	44.0	198.0	13.9
90	3	430	9.46	0.09	121.8	43.0	187.5	13.4
100	2			0.15	87.0	42.0	199.0	13.3
110	2			0.10	92.8	45.0	194.0	14.0
120	2	420	9.45	0.10	81.2	43.0	197.8	13.8

Automatic backwash, 5-minute interval.

TABLE A12. BACKWASH PROGRAM INSTRUCTION LINE

Run Number	Number of Backwashes	Seconds in Pump Run	Seconds in Exhaust
15 & 16	1	3	3
17 & 18	1	1	1
19 & 20	1	2	1
21 & 22	2	3	3
23 & 24	2	1	1
25 & 26	2	2	1
27 & 28	2	3	2
29 & 30	2	2	3
31 & 32	2	2	4

TABLE A13. Run 15, 30 March 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	140	200	330	110	11.4		
10	90	140	330	105	9.8		10.9
20	50	100	320	120	8.6	0.70	8.5
30	5	70	300	140	7.0	0.70	7.2
40	0	60	300	150			6.5
50	0	50	300	150			6.2
60	0	25	300	150	5.2	0.52	5.8
70	0	30	290	160	5.0		5.3
80	0	15	290	160	4.6		4.8

a. Feedwater conditions: temperature: 17°C, pH: 7.07, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 240. Comments: 10-minute backwash intervals; 24.67 gal/8 backwashes = 3.1 gal/backwash; 523.21 gal/72 minutes = 7.27 gpm average product flow; 4.5 percent loss backwash.
b. KPa, gauge.
c. Psi, gauge.

TABLE A14. Run 16, 30 March 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	80	130	320	105	10.1	1.10	
10	20	70	310	120	7.1		8.1
20	0	55	300	130	6.0	0.32	6.3
30	0	40	300	140	5.2		6.0
40	0	30	295	145	4.9		5.4
50	0	20	300	145	4.5		5.0
60	0	10	300	145	4.3	0.42	4.8
70	0	0	300	150	3.9		4.3
80	0	20	310	145	3.7		4.6

a. Feedwater conditions: temperature: 17°C, pH: 7.07, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 240. Comments: 10-minute backwash intervals; 28.26 gal/8 backwashes = 3.5 gal/backwash; 410.83 gal/72 minutes = 5.71 gpm average product flow; 6.4 percent loss backwash.
b. KPa, gauge.
c. Psi, gauge.

TABLE A15. Run 17, 31 March 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	100	150	330	135	10.3	2.00	
10	20	80	315	150	6.9		7.7
20	0	60	300	150	5.4	0.68	6.7
30	0	30	280	140	4.6		5.7
40	0	20	260	140	4.3	0.22	5.4
50	0	40	340	170	5.2		5.6
60	0	30	320	180	4.5		5.2
70	0	30	310	180	4.3	0.55	5.0
80	0	10	310	180	4.0	0.55	4.3

a. Feedwater conditions: temperature: 17°C, pH: 7.07, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 240. Comments: 10-minute backwash intervals; 14.4 gal/8 backwashes = 1.8 gal/backwash; 400.6 gal/72 minutes = 5.55 gpm average product flow; 3.6 percent loss backwash.

b. KPa, gauge.

c. Psi, gauge.

TABLE A16. Run 18, 1 April 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	60	110	270	210	9.3	14.00	
10	80	120	300	170	5.4	9.00	7.7
20	10	60	200	90	8.2	1.60	6.7
30	0	50	180	90	5.5	0.75	5.7
40	0	50	220	100	5.1		5.4
50	0	40	220	90	4.9	0.55	5.6
60	0	30	195	80	4.8		5.2
70	0	20	195	80	4.5	0.22	5.0
80	0	10	190	90	4.3	0.22	4.3

a. Feedwater conditions: temperature: 17°C, pH: 7.1, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 270. Comments: 10-minute backwash intervals; 27.9 gal/8 backwashes = 3.5 gal/backwash; 400.6 gal/72.5 minutes = 5.8 gpm average product flow; 6.6 percent loss backwash.

b. KPa, gauge.

c. Psi, gauge.

TABLE A17. Run 19, 1 April 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	100	160	330	140	10.3	1.40	
10	70	120	320	130	8.9	1.00	9.1
20	0	60	250	120	7.2	0.70	7.2
30	20	70	320	150	6.9		7.7
40	0	60	320	170	5.9	0.48	6.4
50	0	50	300	160	5.4	0.34	6.3
60	0	40	320	180	5.1	0.40	6.0
70	0	30	320	180		0.45	5.8
80	0	20	310	180		0.42	5.3

a. Feedwater conditions: temperature: 17°C, pH: 7.1, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 270. Comments: 10-minute backwash intervals; 47.07 gal/8 backwashes = 5.9 gal/backwash; 497.23 gal/80 minutes = 6.21 gpm average product flow; 8.6 percent loss backwash.
b. KPa, gauge.
c. Psi, gauge.

TABLE A18. Run 20, 1 April 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	50	110	300	160	9.0	0.90	
10	0	80	300	160	7.0	0.85	8.1
20	0	50	260	170	5.9		6.4
30	0	50	300	190	5.5	0.32	6.1
40	0	35	310	200	4.8	0.55	5.5
50	0	20	310	190	4.6	0.40	5.1
60	0	5	310	200	4.2	0.55	4.6
70	0	5	310	200	4.0		4.3
80	0	0	310	200	3.7	0.34	4.1

a. Feedwater conditions: temperature: 17°C, pH: 7.1, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 270. Comments: 10-minute backwash intervals; 21.1 gal/8 backwashes = 2.6 gal/backwash; 400.4 gal/78 minutes = 5.1 gpm average product flow; 5 percent loss backwash.
b. KPa, gauge.
c. Psi, gauge.

TABLE A19. Run 21, 14 April 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	180	190	40	30	13.1	22.00	
10	140	160	40	30	12.6	0.60	13.0
20	140	160	40	30	12.3	0.40	13.0
30	120	150	40	30	11.9	0.38	12.9
40	120	140	40	30	11.5	0.42	12.2
50	110	140	40	30	11.1	0.38	12.8
60	100	120	40	30	10.7	0.36	11.7
70	100	110	40	30	10.4	0.37	11.7
80	100	110	40	30	10.2	0.40	11.2

a. Feedwater conditions: temperature: 17°C, pH: 7.31, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 280. Comments: 10-minute backwash intervals; 35.1 gal/8 backwashes = 6.7 gal/backwash; 843.0 gal/78 minutes = 10.8 gpm average product flow; 6 percent loss backwash.
b. KPa, gauge.
c. Psi, gauge.

TABLE A20. Run 22, 14 April 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	130	160	42	30	12.8	0.32	
10	120	130	42	30	11.4	0.20	12.5
20	120	130	42	30	11.0	0.30	11.9
30	100	110	42	30	10.7	0.25	11.7
40	100	110	42	30	10.3	0.30	11.2
50	100	90	40	30	10.0	0.26	11.0
60	100	110	40	30	9.7	0.34	11.0
70	80	90	42	30	9.6	0.32	10.8
80	80	90	42	30	9.6	0.41	10.8

a. Feedwater conditions: temperature: 17°C, pH: 7.3, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 280. Comments: 10-minute backwash intervals; 22 gal/8 backwashes = 2.75 gal/backwash; 772 gal/75 minutes = 10.3 gpm average product flow; 3 percent loss backwash.
b. KPa, gauge.
c. Psi, gauge.

TABLE A21. Run 23, 15 April 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	140	160	42	30	12.5	0.80	
10	100	110	42	30	10.1	0.40	9.8
20	40	40	42	30	6.7	0.40	7.1
30			42	30	4.8	0.38	4.6
40							
50							
700							

a. Feedwater conditions: temperature: 17°C, pH: 7.3, TOC: 50 mg/liter, turbidity: 130 NTU, conductivity: 270. Comments: 10-minute backwash intervals; 7 gal/3 backwashes = 2.3 gal/backwash; 230 gal/30 minutes = 7.6 gpm average product flow; 3 percent loss backwash; run terminated due to flux decline at 30 minutes.

b. KPa, gauge.

c. Psi, gauge.

TABLE A22. Run 24, 18 April 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	90	110	44	30	11.0	0.55	
10	50	50	45	31	7.6	0.48	8.0
20	10	0	46	31	6.2	0.35	6.9
30	10	0	46	31	4.9	0.38	5.8

a. Feedwater conditions: temperature: 17°C, pH: 7.25, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 285. Comments: 10-minute backwash intervals; 30 gal/7 backwashes = 4.3 gal/backwash; 519 gal/67 minutes = 7.7 gpm average product flow; 4 percent loss backwash; run terminated due to flux decline at 30 minutes.

b. KPa, gauge.

c. Psi, gauge.

TABLE A23. Run 25, 18 April 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	120	150	42	30	11.7	1.10	
10	90	110	42	30	9.9	0.52	11.4
20	80	90	42	30	8.7	0.52	10.0
30	70	70	42	30	8.1	0.40	9.0
40	60	50	42	30	7.6	0.30	8.5
50	50	50	42	30	7.0	0.42	7.9
60	50	40	40	30	6.6	0.22	7.2
70	40	20	40	30	6.2	0.36	8.4

a. Feedwater conditions: temperature: 17 ^{0}C, pH: 7.25, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 285. Comments: 10-minute backwash intervals; 30 gal/7 backwashes = 4.3 gal/backwash; 519 gal/67 minutes = 7.7 gpm average product flow; 5.5 percent loss backwash.
b. KPa, gauge.
c. Psi, gauge.

TABLE A24. Run 26, 18 April 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	140	160	42	29	12.0	0.30	
10	90	110	42	29	9.9	0.21	10.4
20	60	70	42	29	8.5	0.23	9.6
30	70	60	42	30	8.0	0.22	8.9
40	60	60	42	30	7.7	0.25	8.2
50	60	50	42	30	7.4	0.22	8.2
60	50	50	42	29	7.1	0.38	7.7
70	40	50	42	29	6.9	0.27	7.3

a. Feedwater conditions: temperature: 17 ^{0}C, pH: 7.25, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 285. Comments: 10-minute backwash intervals; 21 gal/7 backwashes = 3.0 gal/backwash; 527 gal/67 minutes = 7.9 gpm average product flow; 4 percent loss backwash.
b. KPa, gauge.
c. Psi, gauge.

TABLE A25. Run 29, 19 April 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	160	190	30	42	12.9	0.89	
10	150	160	30	42	12.1	0.18	12.7
20	130	140	30	42	11.7	0.22	12.2
30	100	120	30	42	10.7	0.24	11.5
40	90	100	30	42	9.8	0.24	10.9
50	80	80	30	42	8.5	0.30	9.8
60	60	50	30	42	7.8	0.24	9.2
70	60	50	30	42	7.9	0.30	9.4

a. Feedwater conditions: temperature: 17°C, pH: 7.35, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 270. Comments: 10-minute backwash intervals; 51 gal/7 backwashes = 7.3 gal/backwash; 660 gal/69 minutes = 9.6 gpm average product flow; 7 percent loss backwash.
b. KPa, gauge.
c. Psi, gauge.

TABLE A26. Run 30, 20 April 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	130	150	42	30	11.5	0.65	
10	100	110	42	30	9.6	0.33	11.5
20	100	110	42	30	10.2	0.30	11.1
30	90	90	42	30	9.5	0.33	10.2
40	80	80	42	29	9.0	0.30	9.8
50	80	80	42	29	8.6	0.33	9.3
60	60	70	42	30	8.2	0.42	8.8
70	60	60	42	30	7.9	0.33	

a. Feedwater conditions: temperature: 17°C, pH: 7.35, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 270. Comments: 10-minute backwash intervals; 67 gal/7 backwashes = 9.6 gal/backwash; 600 gal/68 minutes = 8.8 gpm average product flow; 10 percent loss backwash.
b. KPa, gauge.
c. Psi, gauge.

TABLE A27. Run 31, 20 April 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	110	140	29	42	11.0	0.35	
10	60	70	29	42	8.3	0.35	10.3
20	70	70	30	42	8.4	0.42	8.9
30	50	60	30	42	7.2	0.25	8.2
40	50	40	30	42	6.7	0.30	7.5
50	40	20	30	42	6.1	0.30	6.7
60	10	0	30	42	5.7	0.25	6.1
70	10	0	30	42	5.2	0.30	5.8

a. Feedwater conditions: temperature: 17°C, pH: 7.2, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 280. Comments: 10-minute backwash intervals; 76 gal/7 backwashes = 10.9 gal/backwash; 460 gal/67 minutes = 6.9 gpm average product flow; 14 percent loss backwash.
b. KPa, gauge.
c. Psi, gauge.

TABLE A28. Run 32, 20 April 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	130	150	29	42	11.3	0.20	
10	50	50	29	42	7.3	0.25	8.26
20	40	20	29	42	5.9	0.20	7.0
30	20	0	29	42	5.7	0.35	6.1
40	10	0	29	42	5.2	0.35	5.7

a. Feedwater conditions: temperature: 17°C, pH: 7.2, TOC: 50 mg/ l, turbidity: 140 NTU, conductivity: 280. Comments: 10-minute backwash intervals; 44 gal/4 backwashes = 11 gal/backwash; 253 gal/40 minutes = 6.3 gpm average product flow; 15 percent loss backwash.
b. KPa, gauge.
c. Psi, gauge.

TABLE A29. Run 33, 21 April 1988[a]

Time min	Membrane Pressures Product[b] p1	p2	Feed[c] p3	p4	Product Flow gpm	Product Turbidity NTU	Flow After Backwash
0	140	160	42	28	12.0	0.40	
10	80	80	42	30	8.7	0.40	10.0
20	60	70	42	30	8.1	0.35	8.9
30	50	60	42	30	7.4	0.42	8.1
40	40	40	42	30	6.9	0.40	8.0
50	40	40	42	30	6.4	0.51	7.3
60	40	20	42	30	6.2	0.40	6.9
70	40	10	42	30	6.1	0.40	6.8
80	30	0	42	30	5.8	0.45	6.4

a. Feedwater conditions: temperature: 17°C, pH: 7.2, TOC: 50 mg/liter, turbidity: 140 NTU, conductivity: 280. Comments: 10-minute backwash intervals; 194 gal/8 backwashes = 24.2 gal/backwash; 562 gal/80 minutes = 7.0 gpm average product flow; 25.7 loss backwash.

b. KPa, gauge.

c. Psi, gauge.

APPENDIX B

Effects of Backwash Interval (Runs 1-4), TDS (Runs 5-8) and Temperature (Runs 9-13)

TABLE B1. Run 1, 26 April 1988[a]

Time min	Product Flow gpm	Turbidity NTU	TOC mg/liter
Feed		150.00	109.0
0	12.1	0.82	37.7
30	8.3	0.72	29.3
60	6.9	0.42	29.1
90	5.8	0.62	30.2
91:06[b]	10.6	0.25	
120	6.9	0.42	29.5
150	5.7	0.42	29.4
151:44[b]	10.2	0.20	
180	6.7	0.26	27.2
210	5.6	0.22	25.8

a. Feedwater conditions: concentration soap: 150 mg/liter, pH: 7.19, turbidity: 150 NTU, conductivity: 270. Comment: 10-minute backwash (recycle).
b. Flows and pressure at restart following cleaning.

TABLE B2. Run 2, 27 April 1988[a]

Time min	Product Flow gpm	Turbidity NTU	TOC mg/liter
Feed		140.0	99.0
0	10.7	1.2	35.6

STOPPED AT 10 MINUTES, 57 SECONDS BECAUSE OF LOW PRESSURE READINGS.

Feedwater conditions: concentration soap: 150 mg/liter, pH: 7.45, turbidity: 130-140 NTU, conductivity: 270.

TABLE B3. Run 3, 28 April 1988[a]

Time min	Product Flow gpm	Turbidity NTU	TOC mg/liter
Feed		140.0	92.0
0			26.0
30			29.0
60			27.0
90			27.2
91:31[b]	9.9	0.45	
120			24.0
150			24.0

a. Feedwater conditions: concentration soap: 150 mg/liter, pH: 7.29, turbidity: 140 NTU, conductivity: 280. Comment: 5-minute backwash (recycle).
b. Flows and pressures following restart after cleaning.

TABLE B4. Run 4, 27 April 1988

Time min	Product Flow gpm	Turbidity NTU	TOC mg/liter
Feed		150.00	90.0
0	10.0	0.34	32.6
20	5.4	0.34	35.1

SHUTDOWN DUE TO PRESSURE DROP.

Feedwater conditions: concentration soap: 150 mg/liter, pH: 7.35, turbidity: 150 NTU, conductivity: 260. Comment: 5-minute backwash (recycle).

TABLE B5. Run 5, 29 April 1988[a]

Time min	Product Flow gpm	Turbidity NTU	TOC mg/liter
Feed		150.00	87.5
0	10.2	0.35	31.6
20	7.3		
30	6.4	0.42	33.0
40	5.7	0.40	33.5

SHUTDOWN AFTER 40 MINUTES DUE TO LOW PRESSURE.

Feedwater conditions: concentration soap: 150 mg/liter, pH: 7.65, turbidity: 150 NTU, conductivity: 2,500, KCL added to 3,000 mg/liter. Comment: 5-minute backwash (recycle).

TABLE B6. Run 6, 4 May 1988[a]

Time min	Product Flow gpm	Turbidity NTU	TOC mg/liter
Feed		150.00	
0	10.1	0.25	
10	5.2	0.25	

Feedwater conditions: concentration soap: 150 mg/liter, pH: 7.03, turbidity: 150 NTU, conductivity: 1,600, KCl added to 1,500 mg/liter. Comment: 5-minute backwash (recycle).

TABLE B7. Run 7, 5 May 88[a]

Time min	Product Flow gpm	Turbidity NTU	TOC mg/liter
Feed		94.00	
0	10.3	0.40	
30	5.5	0.35	
50	4.7	0.32	

STOPPED AT 50 MINUTES DUE TO LOW PRESSURE.

Feedwater conditions: concentration soap: 75 mg/liter, pH: 6.95, turbidity: 94 NTU, conductivity: 900, KCl added to 750 mg/liter. Comment: 5-minute backwash.

TABLE B8. Run 8, 6 May 1988[a]

Time min	Product Flow gpm	Turbidity NTU	TOC mg/liter
Feed		94.00	
0	9.4	0.30	
30	6.1	0.35	
60	5.8	0.35	
90	5.7	0.38	
120	5.1	0.40	
220	4.[illegible]		
230	4.7	0.48	
233	4.7	0.48	

Feedwater conditions: concentration soap: 75 mg/liter, pH: 6.95, turbidity: 94 NTU, conductivity: 900, KCl added to 750 mg/liter. Comment: 5-minute backwash (recycle).

TABLE B9. Run 9, 11 May 1988[a]

Time min	Product Flow gpm	Turbidity NTU	Temperature C^{o}
Feed		86.00	46.5
0	10.9	0.40	43.0
30	1.9	0.30	43.0
60	1.9	0.35	43.0

STOPPED DUE TO LOW FLOW.

Feedwater conditions: concentration soap: 75 mg/liter, pH: 7.32, turbidity: 86 NTU, conductivity: 300, temperature: 40°C. Comment: 5-minute backwash (recycle).

TABLE B10. Run 10, 11 May 1988[a]

Time min	Product Flow gpm	Turbidity NTU	Temperature C°
Feed		86.00	
0	9.6	0.40	43.6
30	1.0	0.45	43.6

STOPPED DUE TO LOW FLOW.

Feedwater conditions: concentration soap: 75 mg/liter, pH: 7.32, turbidity: 86 NTU, conductivity: 300, temperature: 40°C. Comment: 5-minute backwash (recycle).

TABLE B11. Run 11, 13 May 1988[a]

Time min	Product Flow gpm	Turbidity NTU	Temperature C°
Feed		86.00	30.5
0	11.0	0.55	30.5
30	3.7	0.83	30.5
60	2.9	0.58	31.1

STOPPED DUE TO LOW FLOW.

Feedwater conditions: concentration soap: 75 mg/liter, pH: 7.32, turbidity: 86 NTU, conductivity: 300, temperature: 40°C. Comment: 5-minute backwash (recycle).

TABLE B12. Run 12, 22 May 1988[a]

Time min	Product Flow gpm	Turbidity NTU	Temperature C°
Feed		78.00	23.6
0	11.0	0.35	23.6
30	3.7	0.40	23.6
60	< 2.5	0.38	23.6

Feedwater conditions: concentration soap: 75 mg/liter, pH: 7.28, turbidity: 78 NTU, conductivity: 240, temperature: 40°C. Comment: 5-minute backwash (recycle).

TABLE B13. Run 13, 24 May 1988[a]

Time min	Product Flow gpm	Turbidity NTU	Temperature C°
Feed		78.00	23.7
0	10.0	0.25	23.7
30	4.1	0.25	23.7
60	3.1	0.28	23.7
90	2.8	0.20	23.7
120	1.9	0.35	23.7

Feedwater conditions: concentration soap: 75 mg/liter, pH: 7.28, turbidity: 78 NTU, conductivity: 240, temperature: 40°C. Comment: 5-minute backwash (recycle).

APPENDIX C

Low-flow Runs (0.5 gpm per cartridge).

TABLE C1. Run 1, 17 November 1988

Sample Number	Time min	Source[a] BC or P	Total Solids mg/liter	TOC mg/liter	COD mg/liter	Hardness mg/liter
1	0	Feed	309.25	130.27	258.0	116.0
2	10	BC	404.50	43.47	151.0	
3	10	P	371.25	0.07	165.0	
4	20	BC	231.50	21.78	83.6	
5	20	P	193.75	54.32	72.5	
6	45	BC	214.50	10.93	66.7	
7	45	P	187.00	10.93	57.0	
8	60	BC	189.00	10.93	62.7	114.0
9	60	P	186.25	0.07	53.9	120.0

BC = before carbon; P = product (after carbon).

TABLE C2. Run 2, 18 November 1988

Sample Number	Time min	Source[a] BC or P	Total Solids mg/liter	TOC mg/liter	COD mg/liter	Hardness mg/liter
10	0	Feed	284.00	97.72	246.0	124.0
11	10	BC	207.25	10.93	63.0	
12	10	P	186.00	0.07	64.0	
13	20	BC	205.75	10.93	60.5	
14	20	P	182.50	0.07	59.4	
15	45	BC	200.50	0.07	59.7	
16	45	P	199.50	BDL[b]	50.6	
17	60	BC	204.50	10.93	59.8	120.0
18	60	P	198.00	21.78	48.7	112.0

a. BC = before carbon; P = products (after carbon).
b. BDL = below detectable limits.

TABLE C3. Run 3, 19 November 1988

Sample Number	Time min	Source[a] BC or P	Total Solids mg/liter	TOC mg/liter	COD mg/liter	Hardness mg/liter
19	0	Feed	261.50	108.57	256.0	134.0
20	10	BC	181.00	10.93	70.8	
21	10	P	157.50	21.78	55.0	
22	20	BC	180.25	86.87	67.3	
23	20	P	166.25	10.93	51.5	
24	45	BC	189.00	32.63	67.8	
25	45	P	158.75	0.07	46.7	
26	60	BC	169.00	21.78	63.3	120.0
27	60	P	140.50	0.07	45.1	106.0

[a] BC = before carbon; P = products (after carbon)

APPENDIX D

GLOSSARY OF TERMS

CFU	colony forming units
COD	chemical oxygen demand
EDTA	ethylenediamine tetraacetic acid
hour	hr
USEPA	U.S. Environmental Protection Agency
gpm	gallons per minute
ml	milliliter
NTU	nephelometric turbidity unit
PBS	phosphate buffered saline
psi	pounds per square inch
SSFM	showering system, field mobile
TDS	total dissolved solids
TOC	total organic carbon
USABRDL	U.S. Army Biomedical Research and Development Laboratory

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